Going Beyond Rigid Aeroshells:

"Enabling Venus and Outer-Planet In-Situ Science Missions with Deployables"

Presenter:

Ethiraj Venkatapathy

Chief Technologist, Entry System and Technology Division

NASA Ames Research Center

Co-Authors:

Gary Allen, Dinesh Prabhu and Todd White

ERC Inc., NASA Ames Research Center

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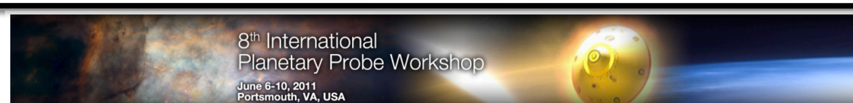
- ADEPT relevant TPS testing was supported by JSC Arc jet group and BRM



Outline and Objective

Objective of this presentation:

- Venus and Outer-Planets (Saturn, Neptune, Uranus) in-situ science explorations are challenging. Part of the challenge is imposed by rigid aeroshell technology.
- Deployable or low ballistic coefficient aeroshell technology is a game changer
  - Very benign entry environment much more enabling of science
- Planned investments by Office of the Chief Technologist, has the potential to change the way we do EDL at Venus, Saturn, Neptune, Uranus, and Mars

Outline:

- High Ballistic Co-effiecient (rigid) Aero-shell Technology (HBCAT)
- Entry at Venus, Saturn and Uranus using Low Ballistic Coefficient Aeroshell Technology (LBCAT)
- ADEPT and Flexible TPS Concepts Under Development
- Concluding Remarks
- Questions?

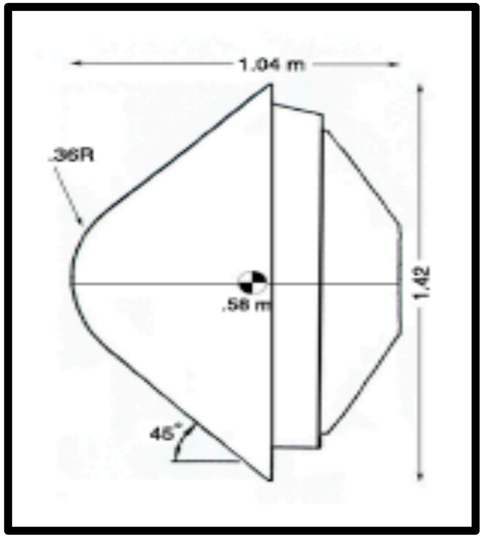
Pioneer-Venus:

P-V Probes: One Large Probe and three identical Small Probes

- Survival was a bonus.
- All but one survived impact, but all probes survived entry
- Entry Velocity 11.5 km/s

Large Probe

- **Ballistic Coefficient: 188 kg/m2; Size 1.42 m**
- **Entry Flight Path Angle: -32.4 deg at 200 km**
- **Peak heat-flux: 4500 W/cm2 (~50% radiative)**
- **Total heat-load (stag): 12.4 KJ/cm2**
- **Peak stagnation pressure: ~10 atm.**
- **Probe Mass: 316.5 kg**
- **Peak deceleration: ~300g**
- **Mass Fraction of Carbon Phenolic TPS: 8.83%**



Our Vision to Explore Venus: Mission Studies:

	Mission	Date	Proposal
1	Venus Flagship Study (JPL Led)	2009	Flagship Study
2	ViTAL: Venus Intrepid Tessera Lander	2010	Decadal Study
3	VCM: Venus Climate Mission	2010	Decadal Study
4	VME: Venus Mobile Explorer	2010	Decadal Study

- **All the missions proposed use scaled P-V shape (45 deg sphere-cone)**
- **Rigid aeroshell with ballistic coefficient ~200 kg/m^2**
- **Carbon Phenolic is the only viable TPS**
- **Large G'load during entry**

VME (2010) : A Flagship Class Mission Study Sponsored by Decadal Survey Committee

Entry Velocity 11.3 km/s; EFPA – 21 deg
Aeroshell Size : 3.5 dia.
Entry Mass: 2921 Aeroshell Mass=1139 kg
Mass fraction of Aeroshell = 40%

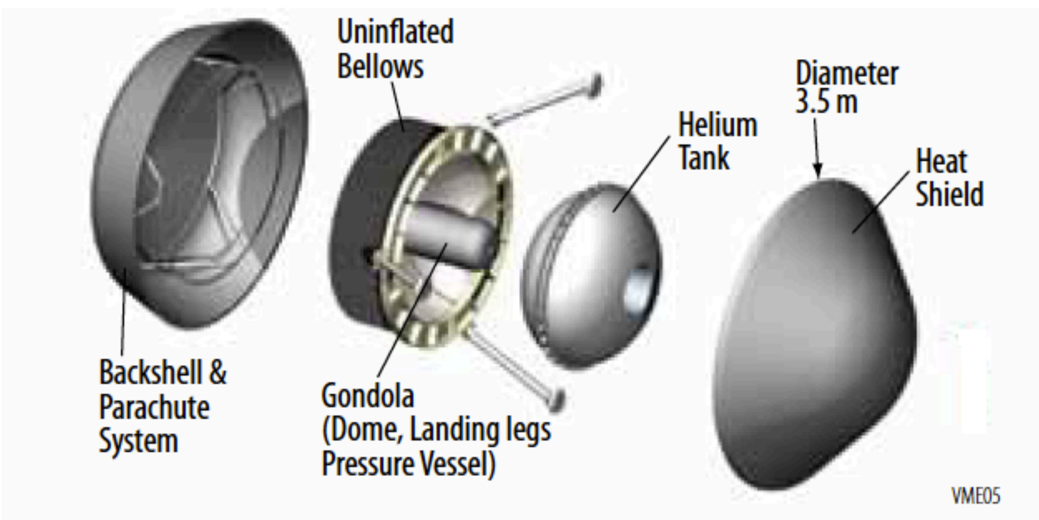
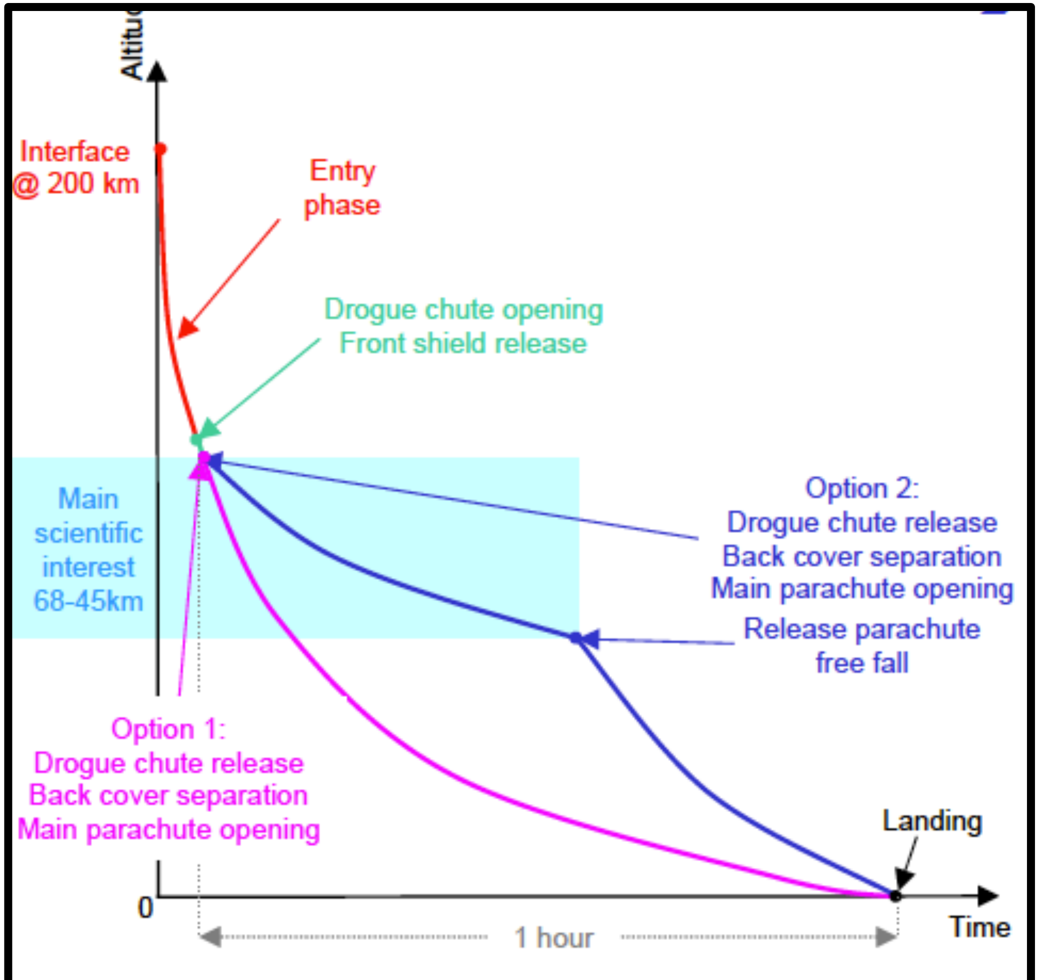


Figure 6: Aeroshell back shell and heat shield are based on Pioneer Venus Large Probe and Stardust geometries.

Table 9: Mission level mass rackup (**Table 6** shows carrier details).

Item	CBE (kg)	Composite Mass Growth Allow. (%)	Max Expected Mass (kg)
Lander	**1390**	30%	**1782**
Lander Science Payload	31	30%	41
Lander Subsystems	469	30%	609
Mechanical/ Structure	270	30%	351
Mechanisms	51	30%	66
Thermal	113	30%	147
Other	34	30%	44
Bellows	890	30%	1132
Aeroshell	**876**	30%	**1139**
Spacecraft	846	30%	1100
Satellite (S/C + Probe) Dry Mass	3112	30%	4021
Propellant Mass	366	1%	370
Satellite Wet Mass	3478		4390
LV Throw Mass available to lift Wet			5141

Selecting EFPA and Ballistic Coefficient: Challenges to consider & Constraints that impacts Science Payload Mass

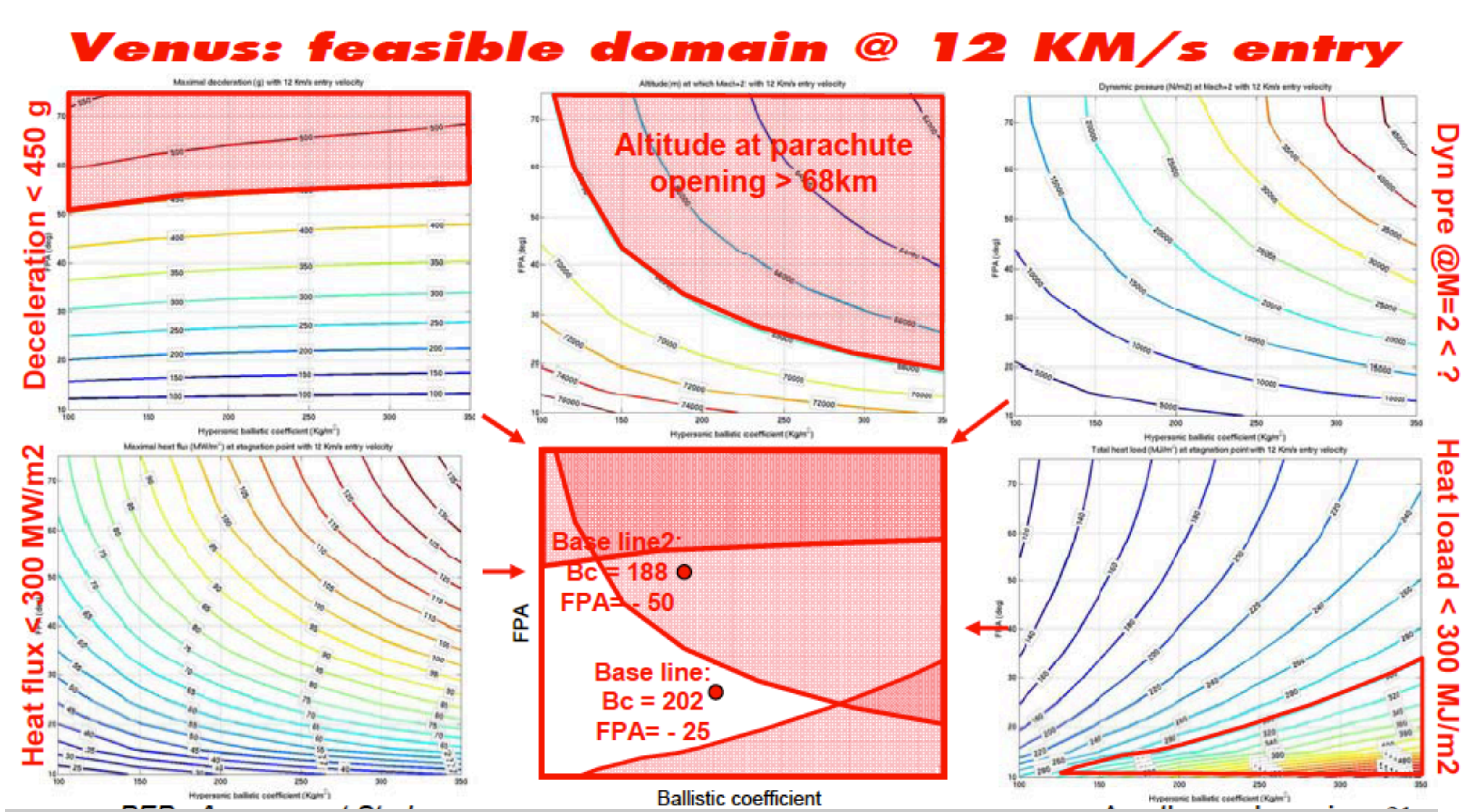


Venus Entry and Descent Constraints:

- Max heat-flux
- Max total pressure
- Total heat load
- Max deceleration
- Max dynamic pressure vs alt.
- Drogue chute opening alt.
- Shield separation assurance
- Sizing main parachute for max descent time (toxic env.)
- Free fall time from 45km to surface (thermal problems)

Acknowledgement: From ESA PEP Study Presentation

Selecting Entry Flight Path Angle and Ballistic Coefficient



Acknowledgement: 2010 ESA Planetary Entry Probe (PEP) Assessment Study

ethiraj.venkatapathy-1@nasa.gov

A Carpet plot of Missions to Venus: High Ballistic Coefficient (P-V Probe Scaled)

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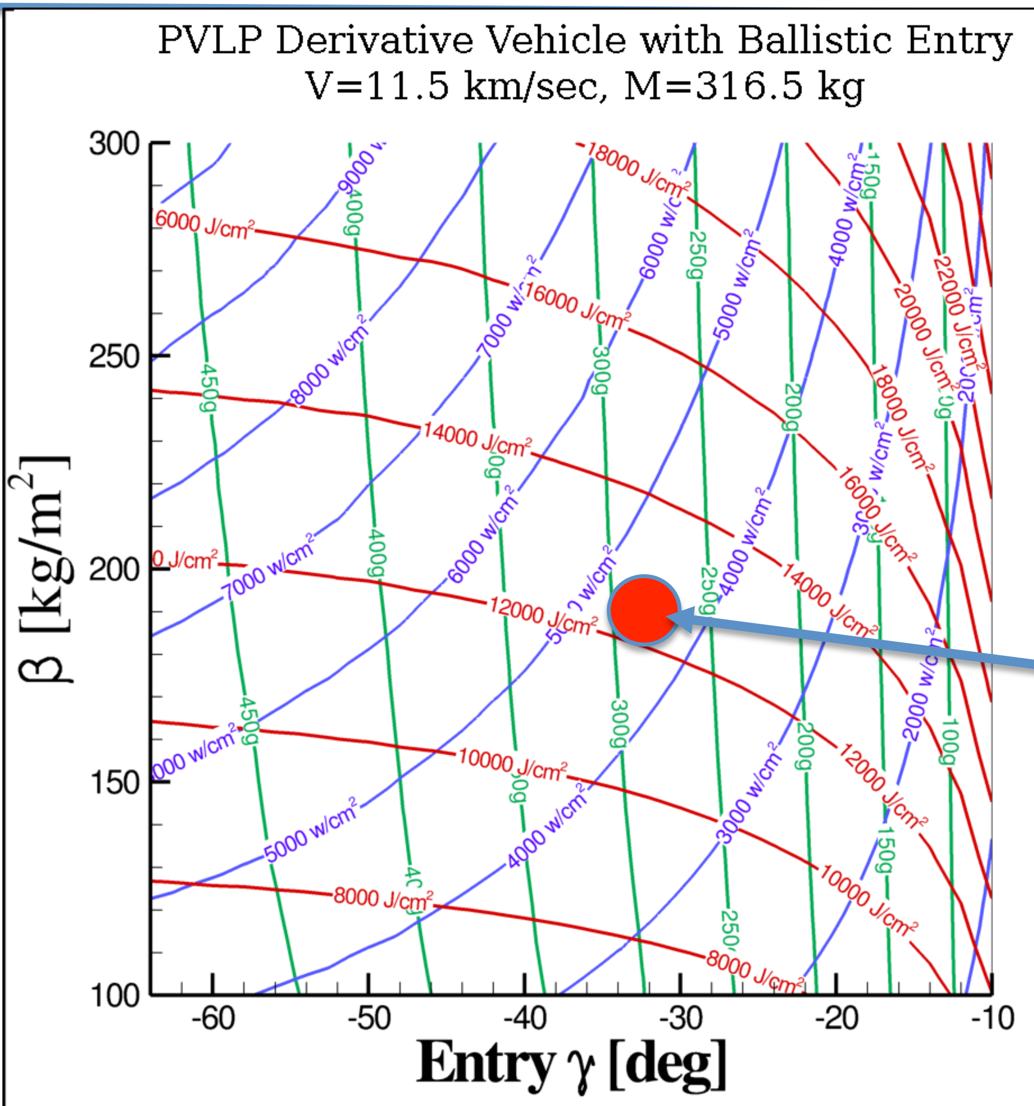
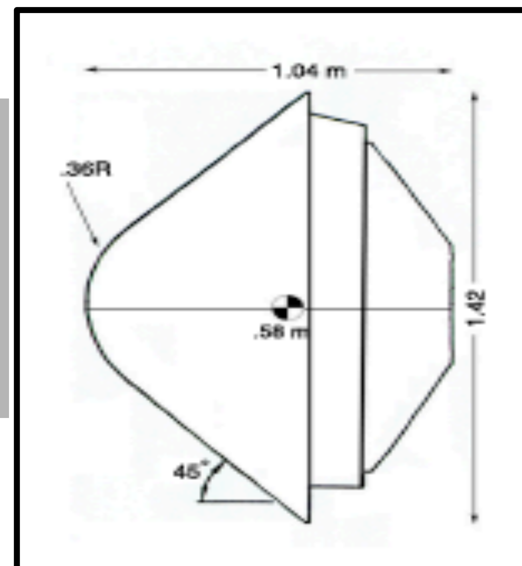
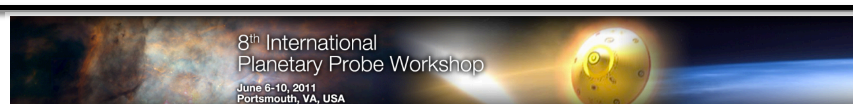


- Skip-out is ~ (-7.5^0)
- Rigid Aeroshell Ballistic Coefficient (200 – 350)
- Entry Flight Path Angle
  - Lower EFP = Increased (heat-load and TPS Mass fraction)
  - Lower Ballistic Coefficient = lower payload mass

P-V Large Probe





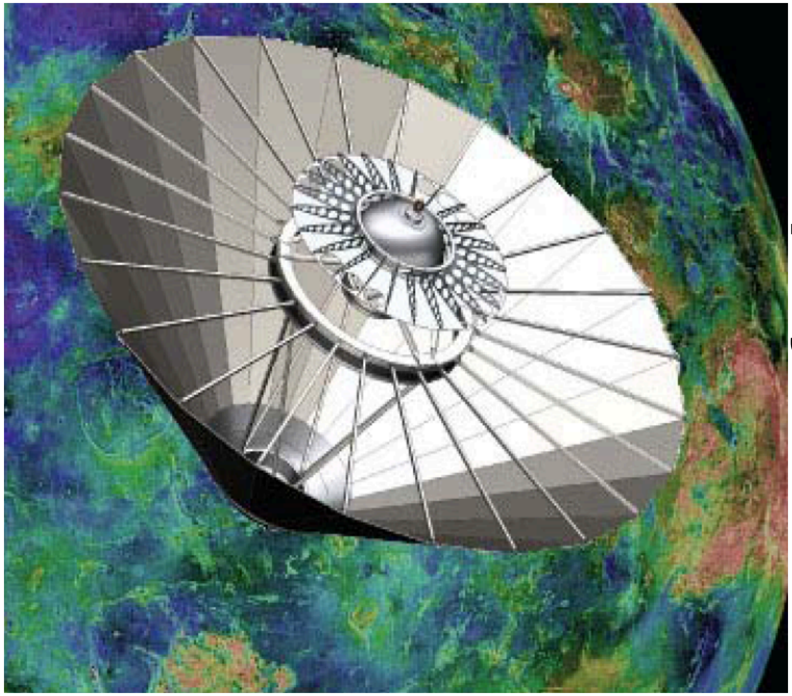
Venus In-situ Missions: High Ballistic Coefficient Rigid Aeroshell Technology (HBCAT) Challenges

High Ballistic Coefficient ~ 200 or higher

- For Heat-flux (2000 – 7000) w/cm^2 stag. pressure (2 – 10) atm, **Carbon phenolic** is the only choice
- Challenges for Carbon Phenolic are:
  - Especially need alternate to heritage, fully dense, chop-molded, Carbon Phenolic.
  - Lack of ground test facilities capabilities
    - Certification of Vendors and processes
    - TPS qualification, and flight heat shield certification
- High G'load during entry (200 g' – 450 g')
  - Robustness to high G' conditions adds mass and verification is a challenge
- 45 deg sphere-cone rigid aeroshell geometry
  - Packaging and C.G. constraints

LOW BALLISTIC COEFFICIENT AEROSHELL TECHNOLOGY (LBCAT)

Inflatable



Mechanically Deployable

If we can fly low ballistic coefficient aeroshell at Venus, what would that buy?

ethiraj.venkatapathy-1@nasa.gov

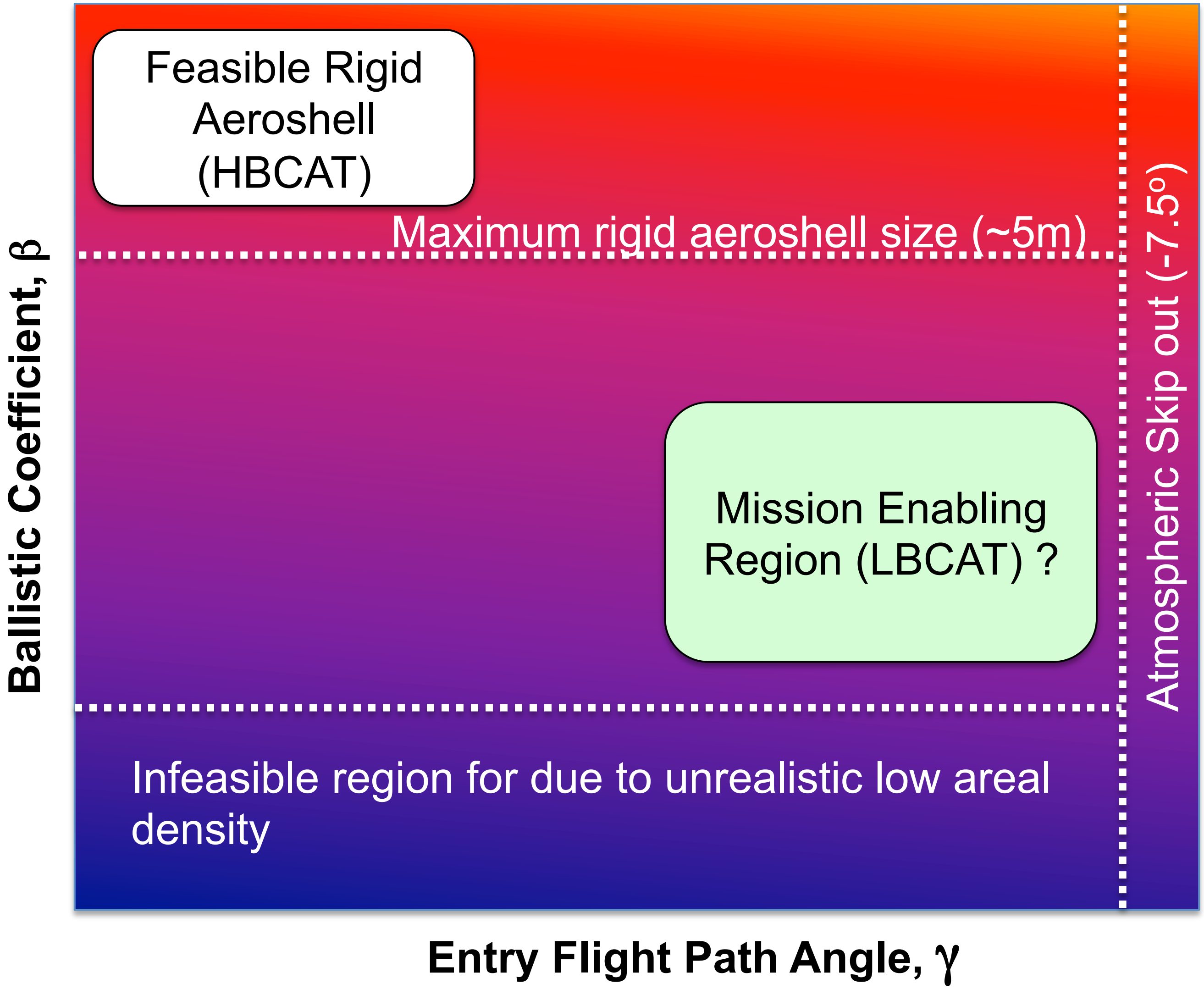
HBCAT and LBCAT

Lowering β
- lower heat-flux
- lower heat-load
- Low entry mass or increased size

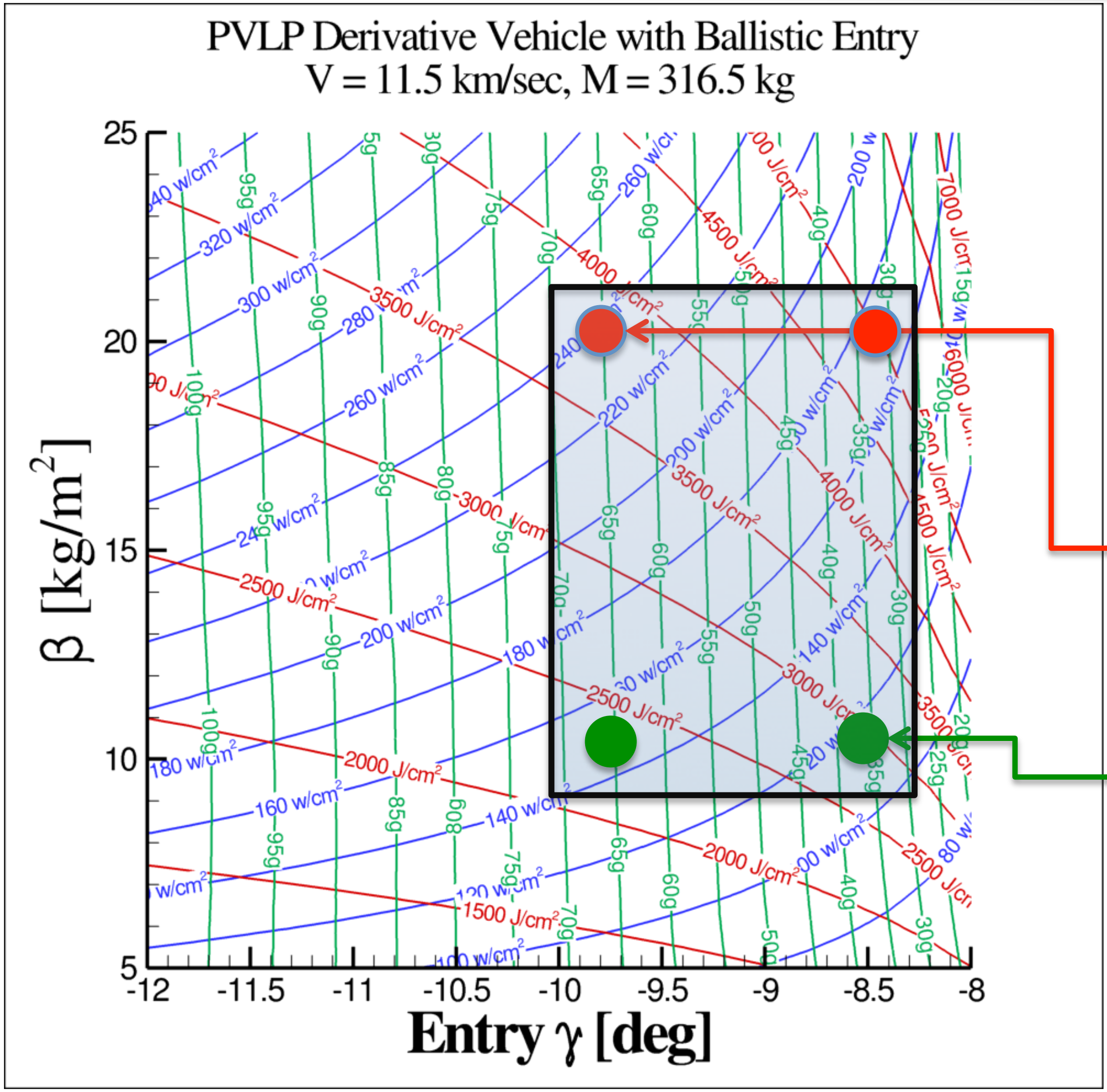
Lowering γ
- lower g'load
- raises heat-load
- raises heat-flux

Best is:

Lower β and γ together sufficiently so that entry mass is not increased significantly



Low Ballistic Coefficient Design Space: (P-V Probe Scaled)

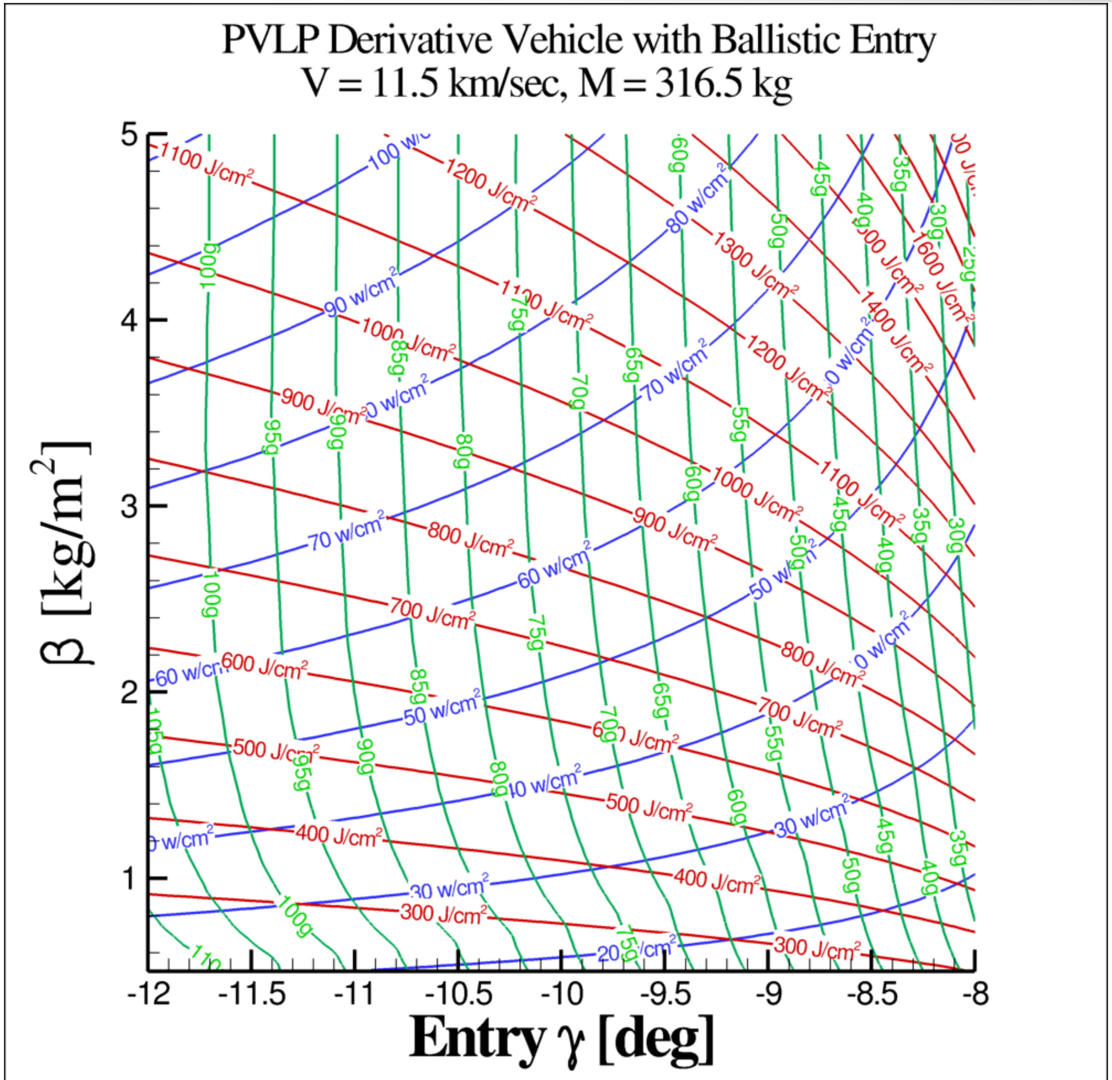


- **Low (Ballistic Coefficient & EFPA)**
  - **Low peak heat flux**
  - **Low G'load**
  - **Low heat load**

B=20 => P-V Large Probe scaled to 4.0 m

B=10 => P-V Large Probe scaled to 6.2 m

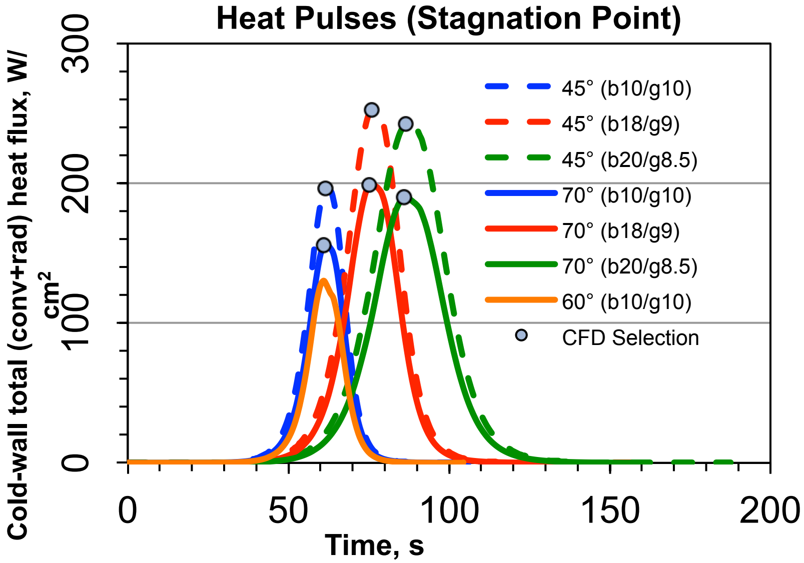
What Happens With Even Lower Ballistic Coefficient in the Design Space?

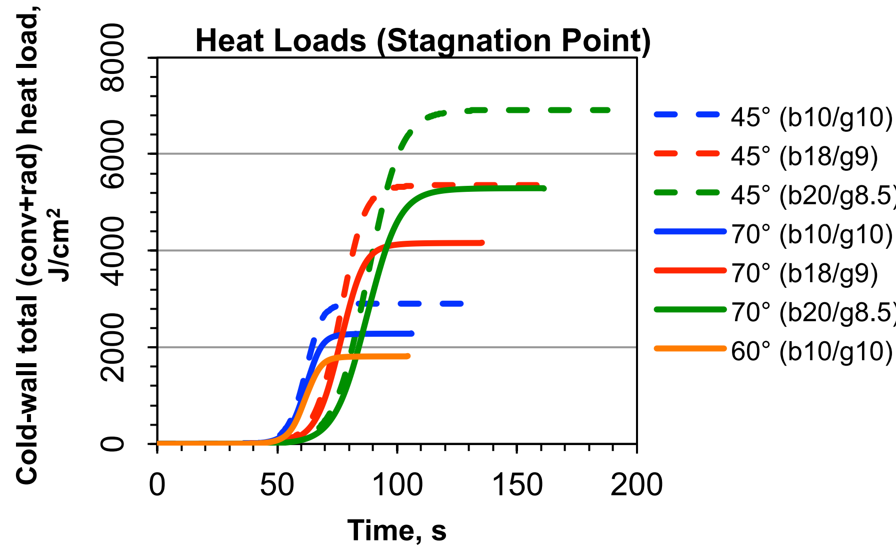


Lower β means

- Lower heat-flux and heat-load
- At β of 5 (dia. = ~8.5m) heat flux (60 – 110 w/cm2)
- At β of 1 (dia. = ~20 m) heat flux (25 – 35 w/cm2)
- If the desire is to stay at very low heat-flux (~30 W/cm2) and have some margin on γ, g-load starts to go back up
- Lower β (<2) => very larger diameter/surface area and higher g-load

LBCAT – Venus - Parametric Study: Stagnation Point Peak Conditions



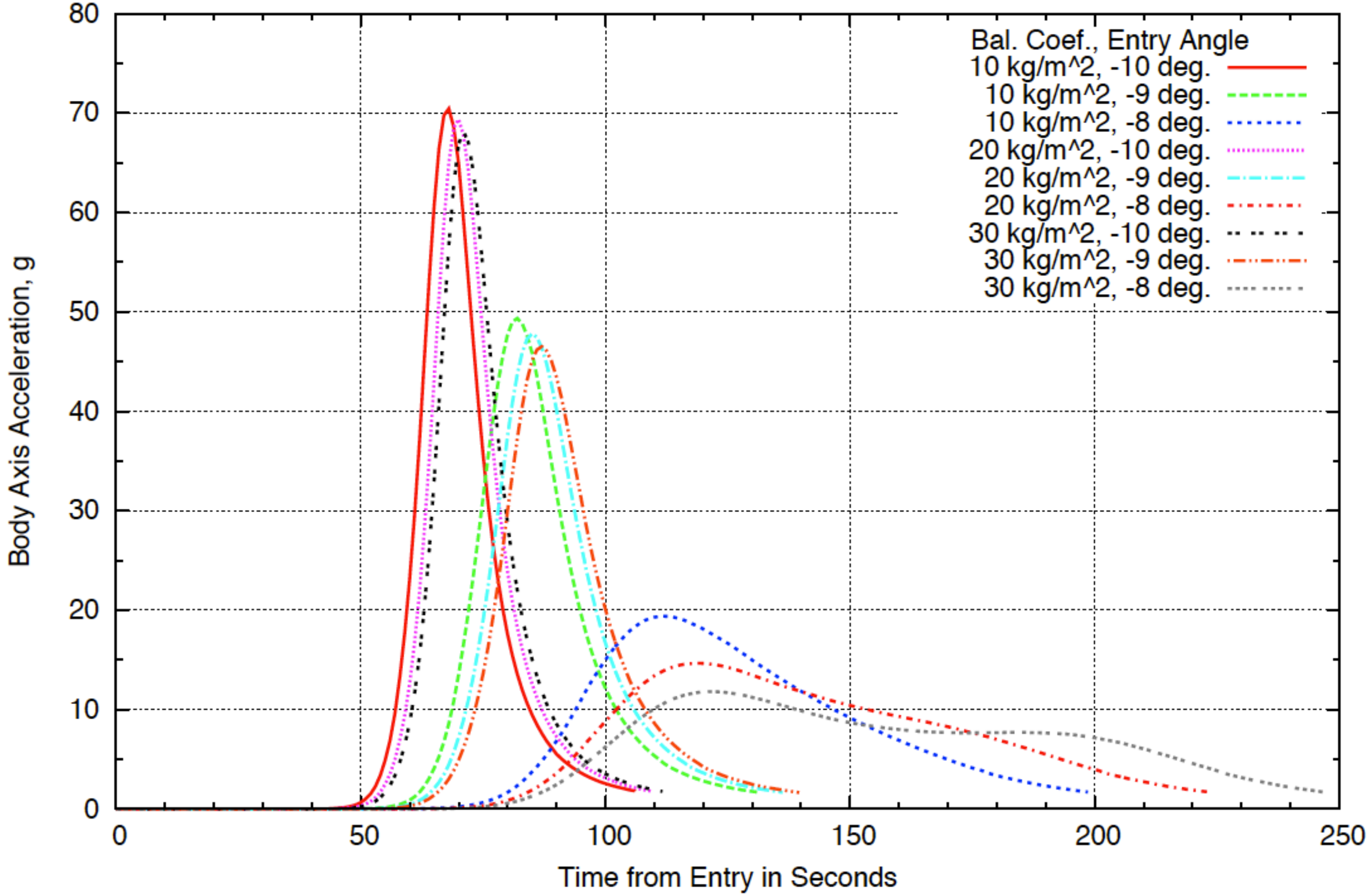


- **Ballistic Coefficient (10 – 30); Entry Mass (300 kg and 3000 kg); EFPA (-8.5, -9 and -10.0); Shapes Considered (70^o, 60^o, 45^o)**

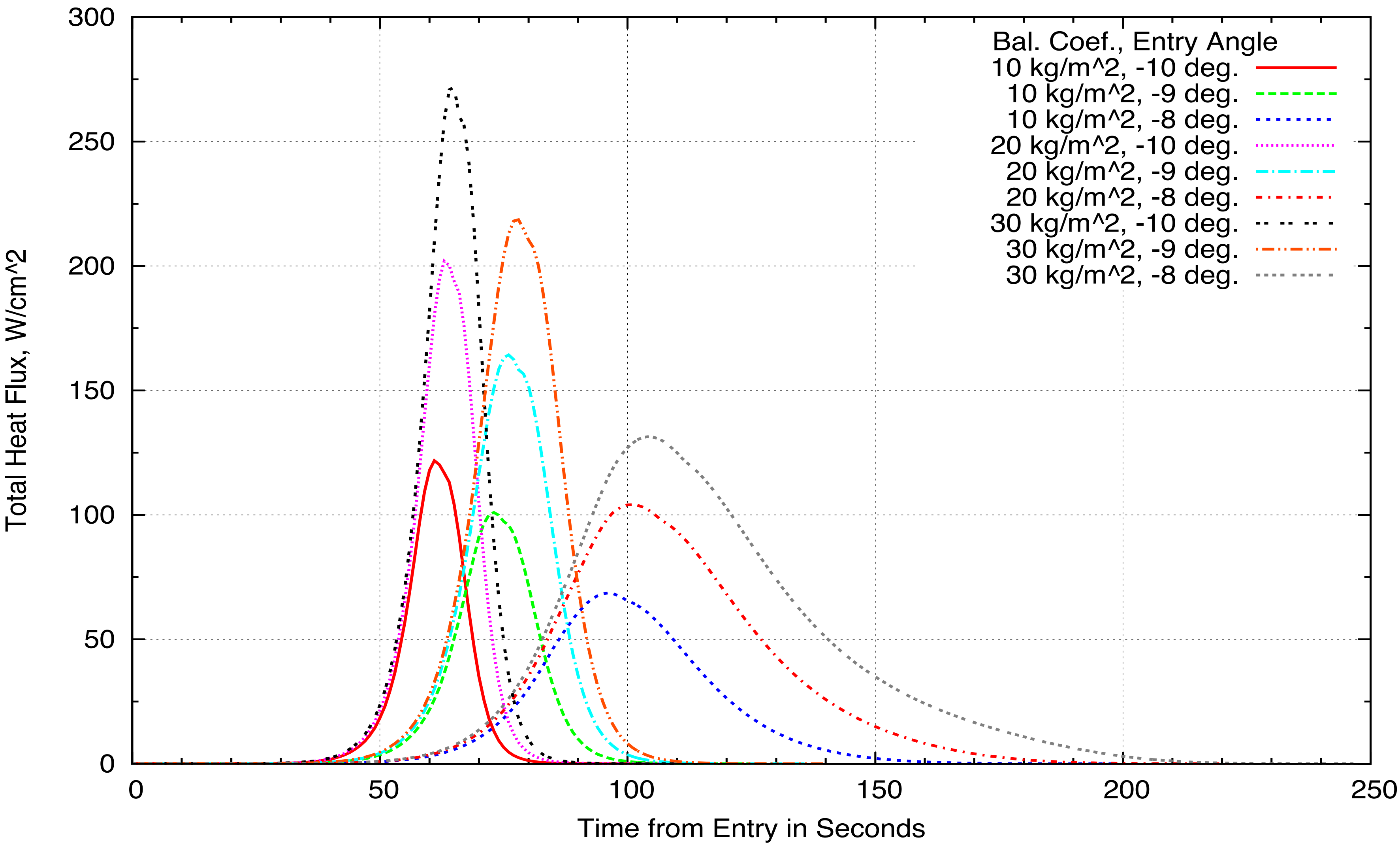
Observations:

- **Low EFPA = Low G'load**
- **Low Ballic Coeff. = Low heat load**
- **Stag. Heat-flux or Pressure not very sensitive**
- **Shape: 60 or 70 deg is more preferable than 45 deg sphere cones**
- **Heat load is sensitive**

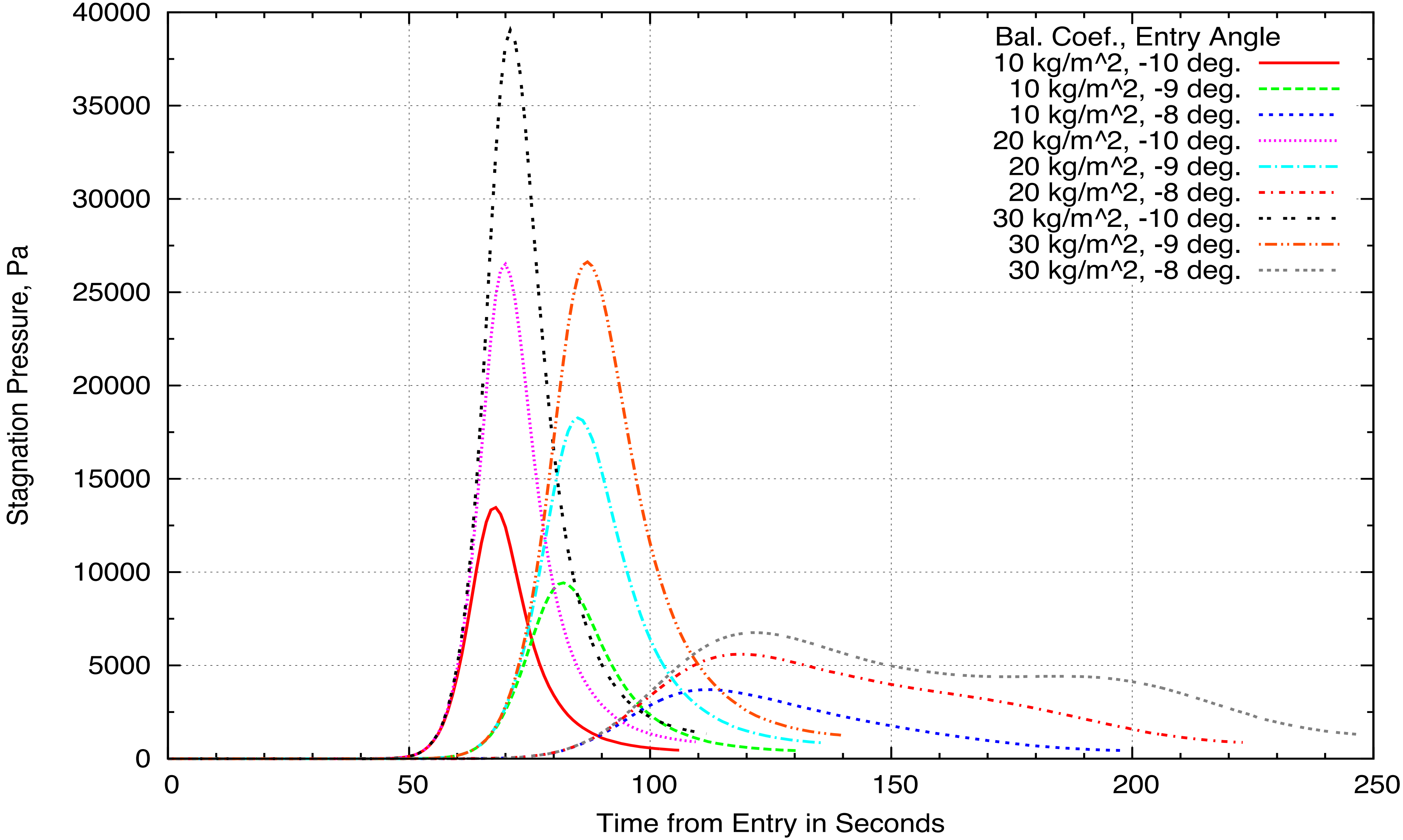
LBCAT for Venus EDL: Deceleration Profile During Entry (Entry Mass = 2000 kg; 70 deg. Sphere-Cone)



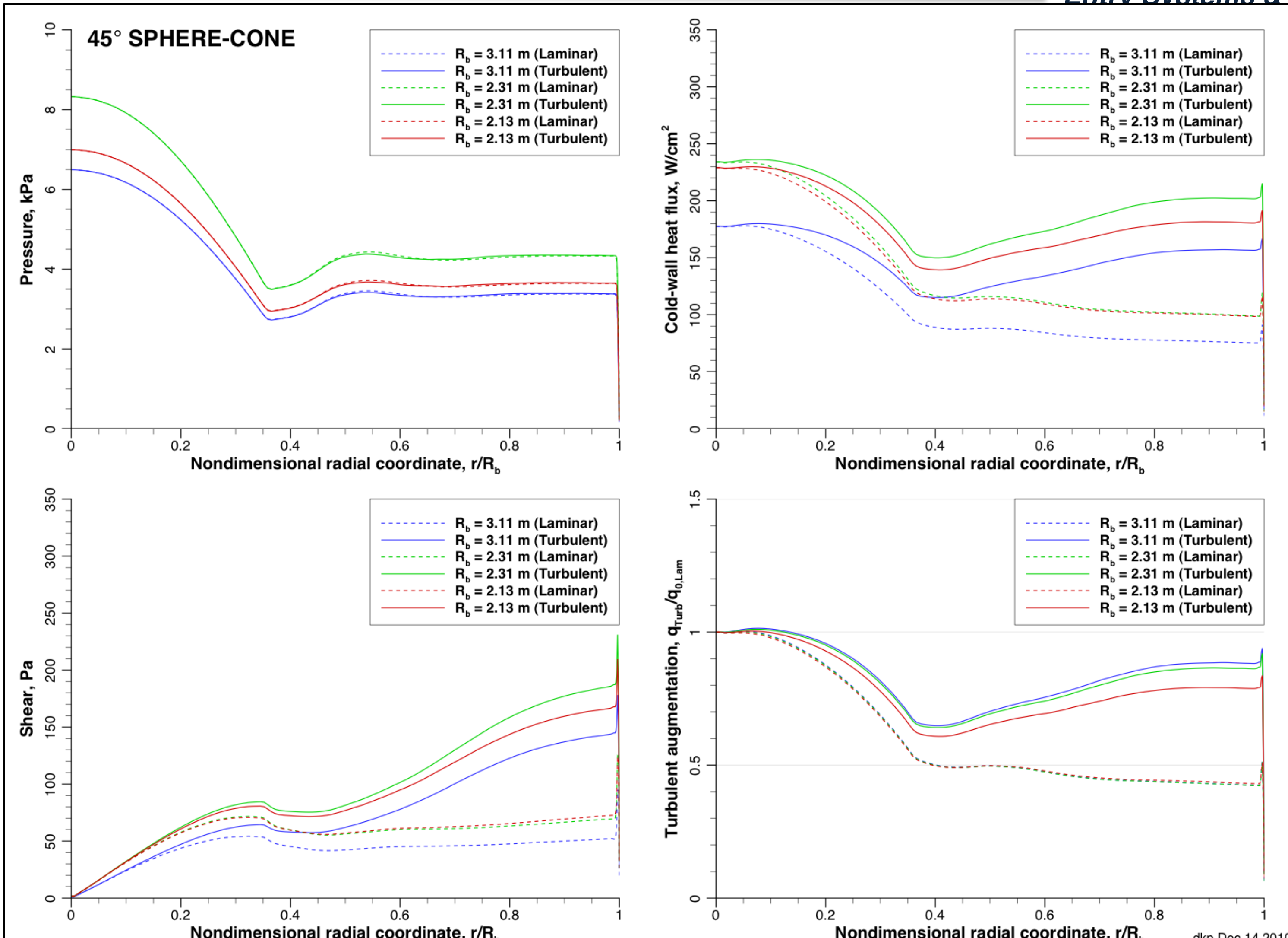
LBCAT for Venus EDL: Stag. Point Total Heat-Flux During Entry (2000 kg Entry Mass and 70^0 Sph.-Cone)

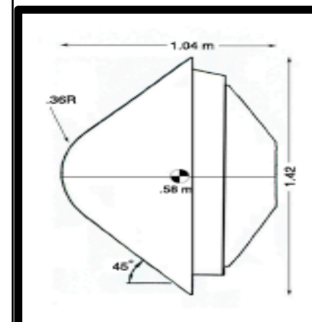


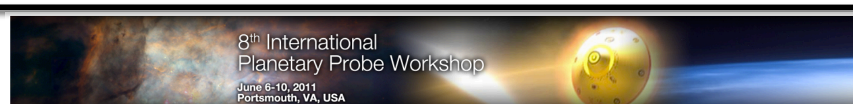
LBCAT for Venus EDL: Stag. Pressure During Entry (2000 kg Entry Mass and 70⁰ Sph.-Cone)



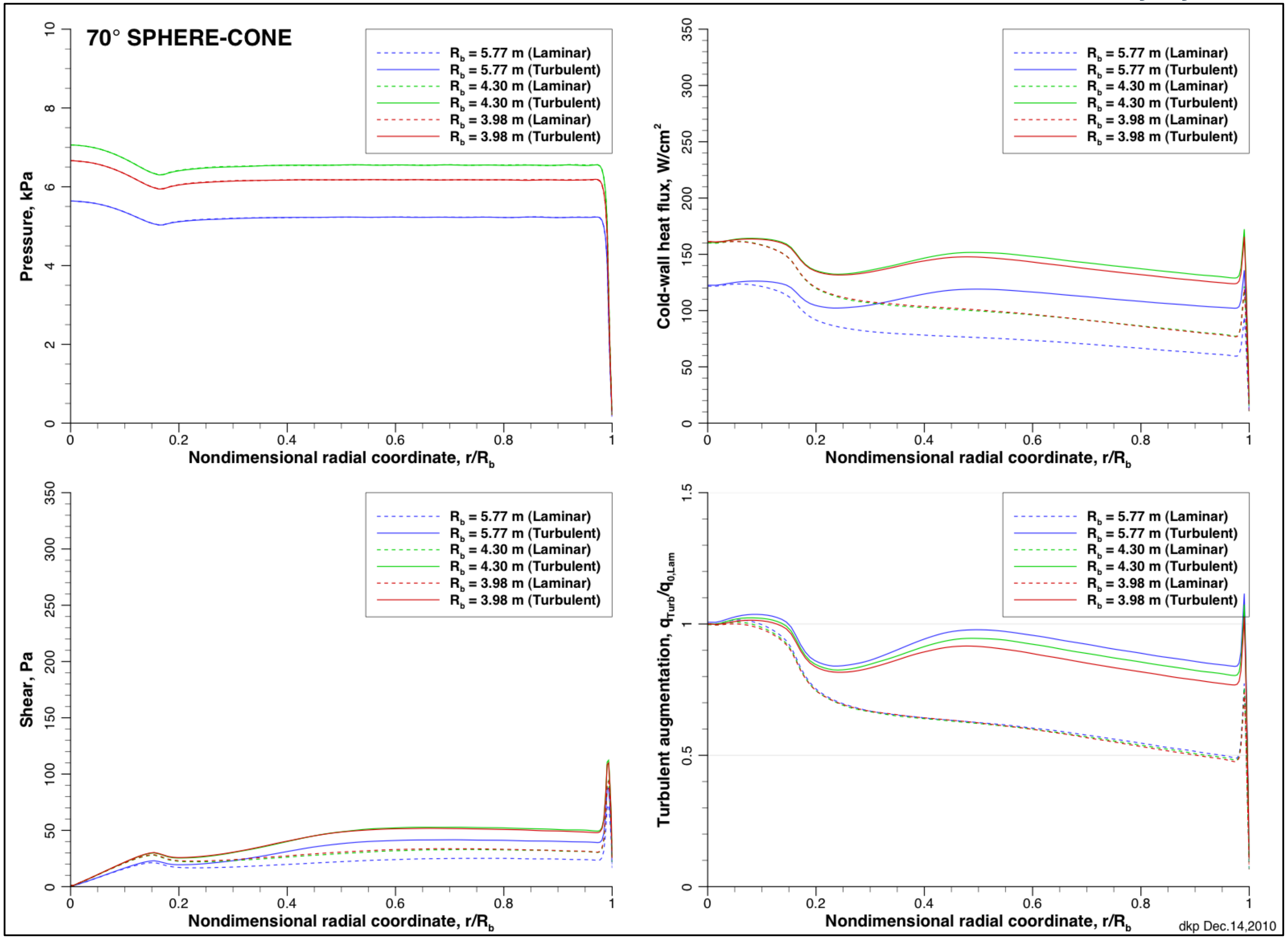
Laminar vs Turbulent Heating at Peak Heat Flux Point Along the Trajectory (45 deg sphere cone Scaled P-V)





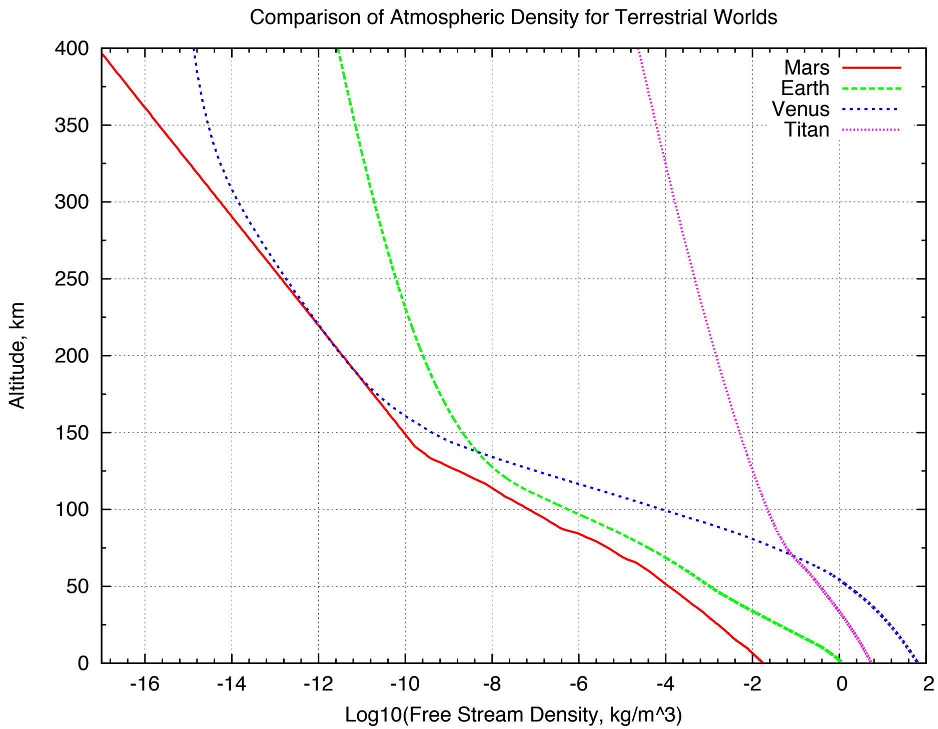


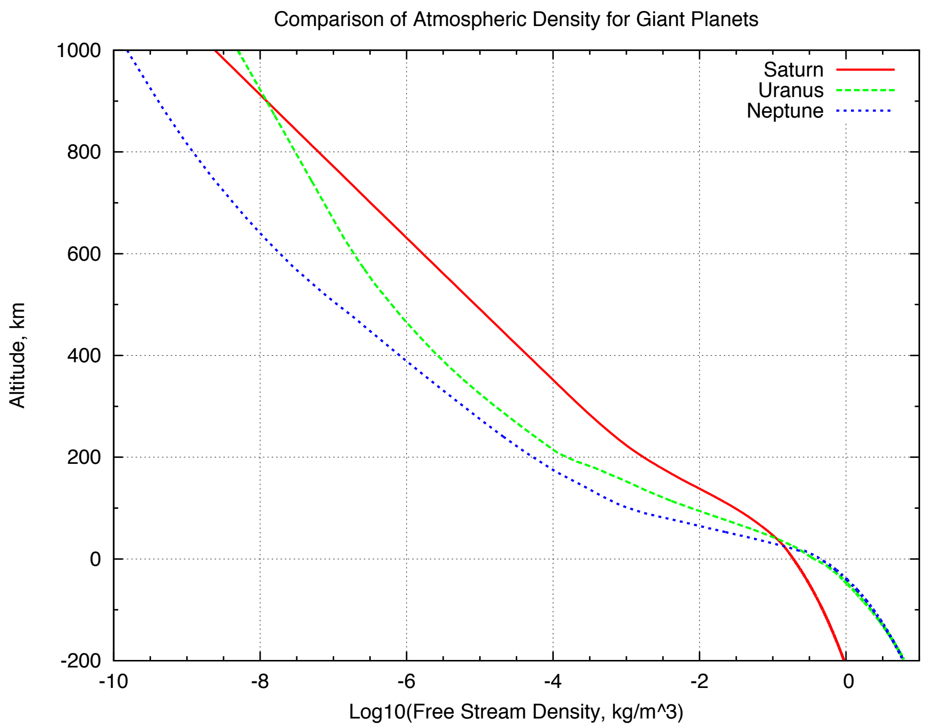
Laminar vs Turbulent Heating at Peak Heating Point Along the Trajectory (70 deg sphere cone Scaled Viking)



What about other Planets?

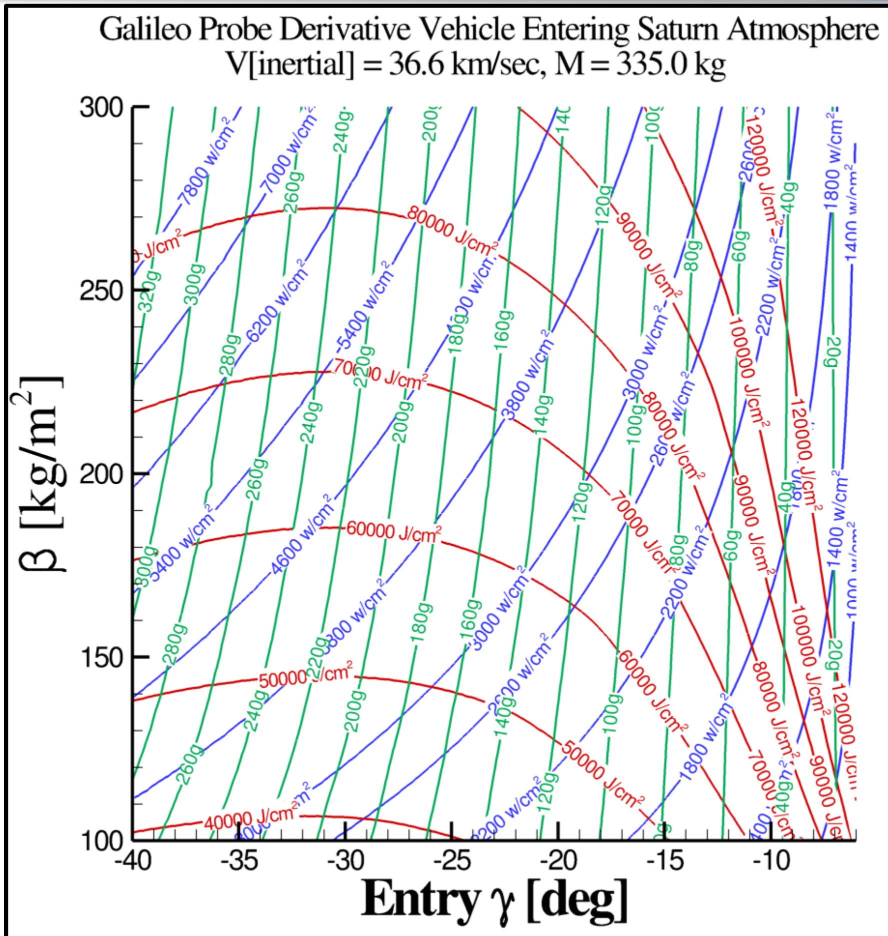
- **Current Missions Studies for Saturn, Neptune and Uranus Probes use rigid aeroshell with high ballistic coefficient**
  - Face similar challenges as Venus
  - High G'load, and high heat-flux and pressure needing Carbon Phenolic



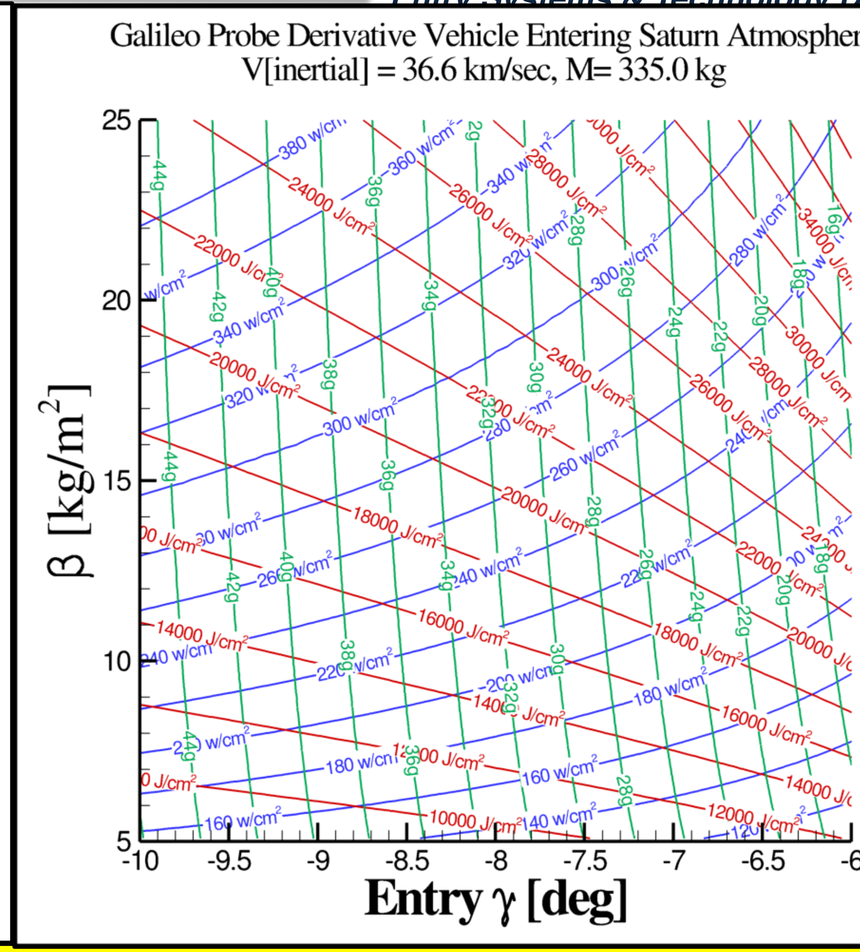


LBCAT for Saturn:

High Ballistic Coefficient Range



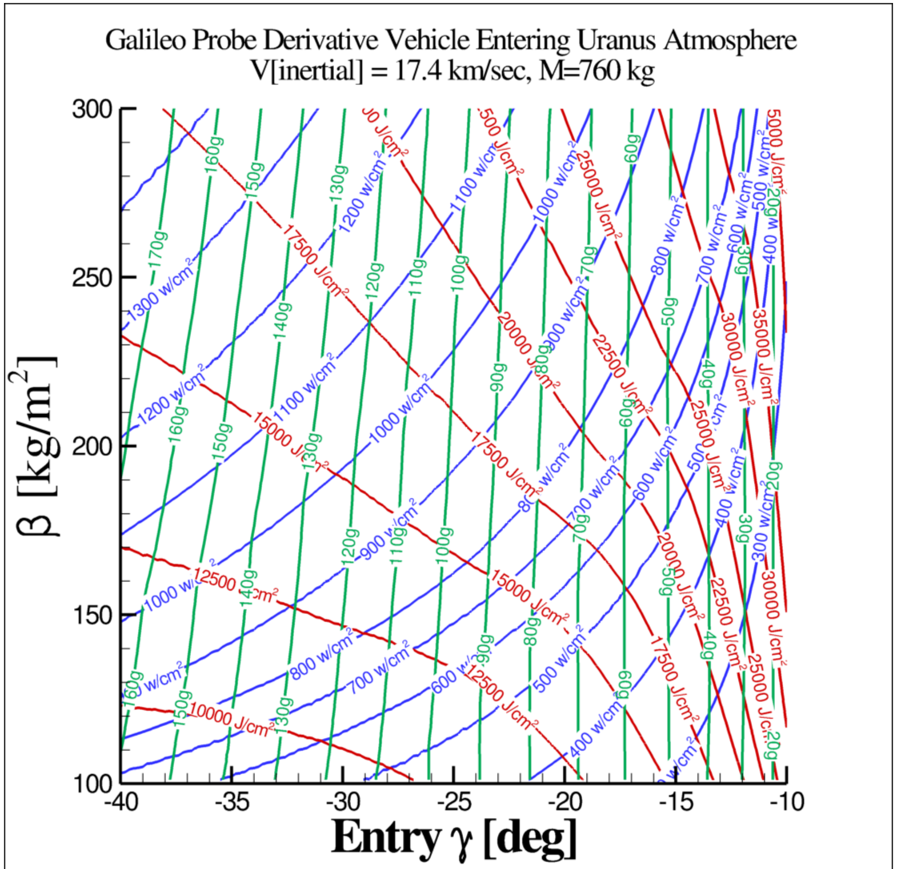
Low Ballistic Coefficient Range



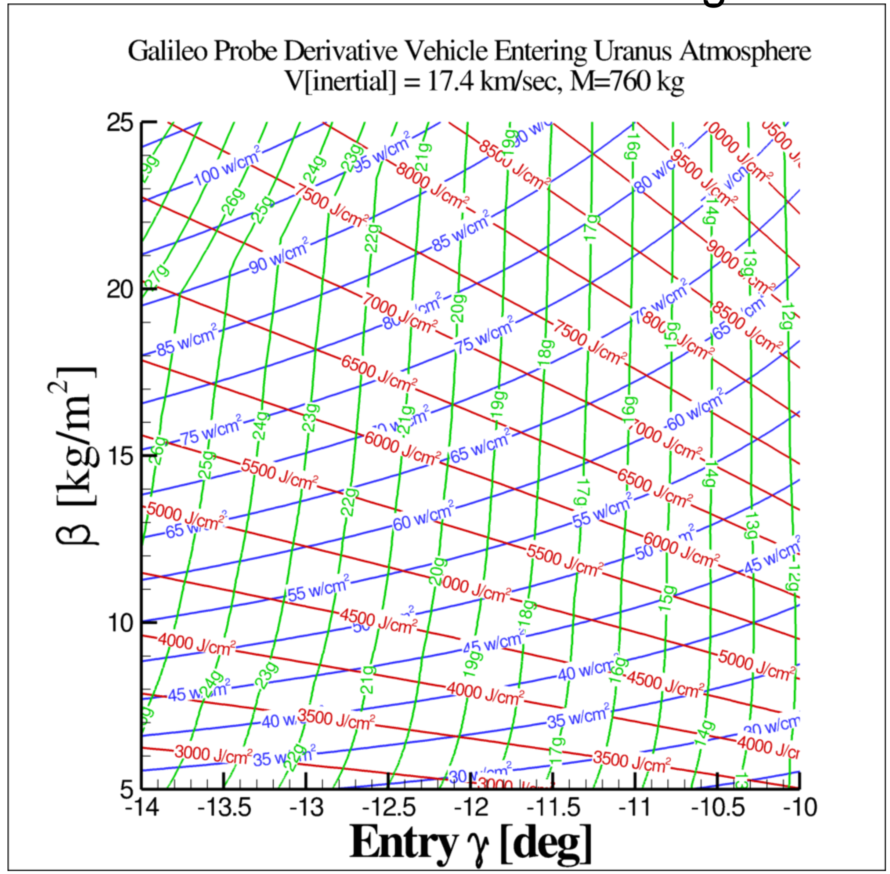
- **LBCAT is as effective at Saturn as well (much reduced entry env.)**
- **Entry conditions are similar to Venus with LBCAT**

LBCAT for Uranus:

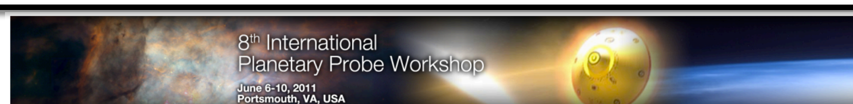
High Ballistic Coefficient Range



Low Ballistic Coefficient Range



- **LBCAT is as effective at Uranus as well (much reduced entry env.)**
- **Entry conditions are similar to Venus and Saturn**



Summary: LBCAT for Venus, Saturn and Uranus (& most likely Neptune)

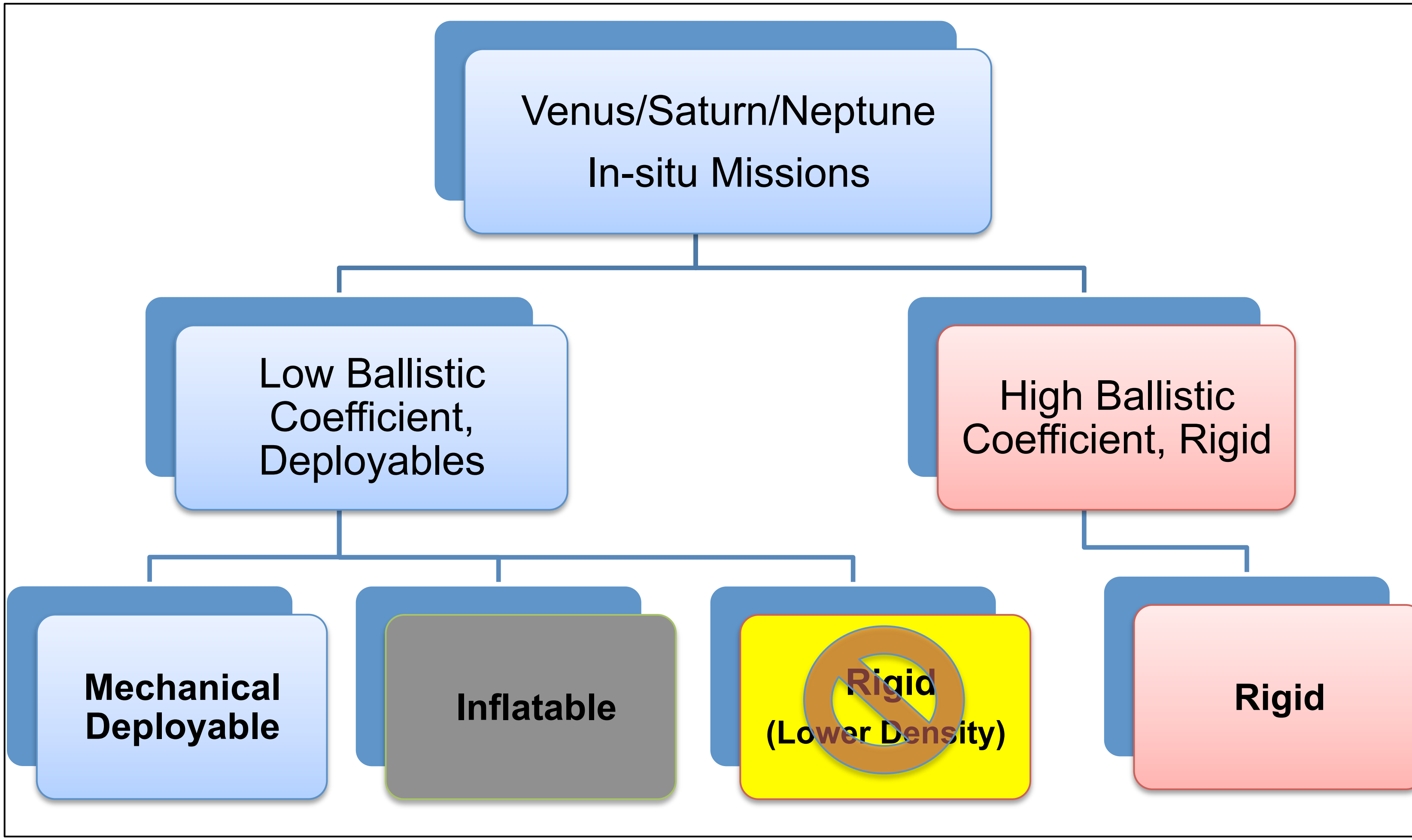
◆ Low Ballistic Coefficient Technology

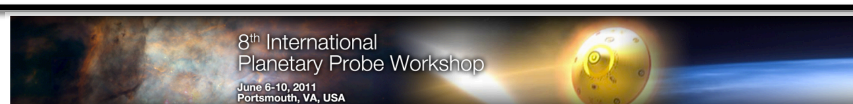
- Results in very benign Entry Conditions
  - Low heat-flux
  - Low pressure
  - Low heat load
  - Low G'load
- Challenges of testing and certification for flight is well within current facility capabilities
- Should result in lower Risk and Cost

◆ Science Enabler

- Allows for inclusion of sensitive instrumentation
- Integration and certification is much easier
- More attractive for integrating ASRG technology

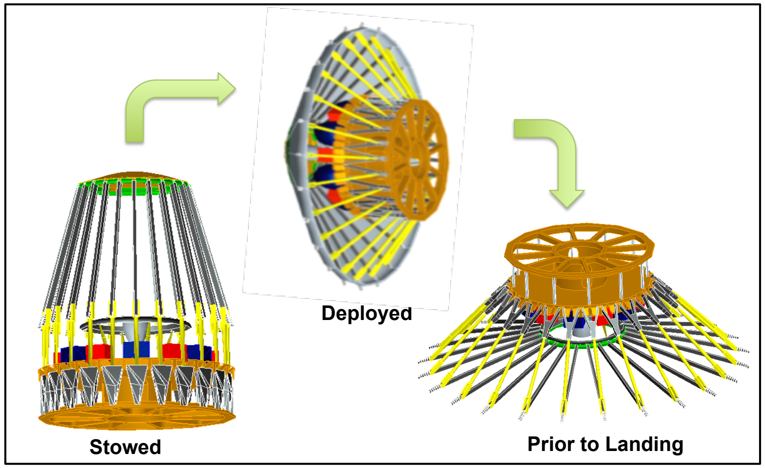
How can we achieve LBCAT?





Deployable Entry System Concepts

- **Adaptable, Deployable Entry and Placement Technology (ADEPT)**
  - Concept study proposed under IPP and completed in Nov 2010



- **Our motivation for exploring Venus, Saturn and Uranus is that it will be a stepping stone for Technologies such as ADEPT and Flexible TPS**
- **OCT is investing in both ADEPT as well as HIAD and the investment will mature these technologies to TRL 5-6 in 3 years.**
- **On going HIAD design at present is looking at inflatable systems with relatively low heat-flux capabilities (< 50 w/cm2)**
- **ADPET is looking at high heat-flux (~250 W/cm^2) capable entry systems**

Flexible, High Heat-flux, Ablative TPS Development:

- **OCT Game Changing Technologies Division is investing in Flexible, Ablative TPS starting (2012 – 2014) leveraging the investment made by ARMD and ESMD mission directorates in the past few years**
  - **3 year project to result in TRL 5-6**
  - **High heat flux (> 250 W/cm2)**
  - **System integration with inflatable or mechanically deployable (ADEPT)**

Concluding Remarks

- **Use of rigid aeroshell (high ballistic coefficient) challenges, though limiting, helped achieve great science in the past**
  - Pioneer-Venus and Galileo
- **Current manufacturing (Carbon-Phenolic) and test facility (arc jet) limitations as well as more demanding mission requirements (value proposition) needs**
  - Alternate architectures and technologies has the potential to make Venus and OP missions less risky and more cost effective
  - This does not mean we are giving up or advocating against Carbon Phenolic
- **OCT is investing in low ballistic coefficient deployable technologies, such as semi-rigid and inflatable, as well as flexible high heat-flux TPS**
- **Successfully maturing these technologies will have "game-changing" impact and enable better science missions**

Reference

1. "Adaptive Deployable Entry and Placement Technology (ADEPT):A Feasibility Study for Human Missions to Mars," E.Venkatapathy, et.al., AIAA Paper #2011-2608, 21st AIAA Aerodynamic Decelerator Systems Technology Conference and Seminar, Dublin, Ireland, 23-26 May 2011